A Recursive Programming Theory of the Residential Land Development Process

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•INTEREST in the land development process has increased in recent years with the growth of urban and regional planning. Planning, by reason of its primary objectives, must influence the land development pattern. An understanding of the land development process is a necessary prerequisite for such an influence since it is difficult to control a process the characteristics of which are not understood.

Attempts to understand the land development process have generally taken form in mathematical models which have been formulated to represent and to simulate over time this process. Although such models have taken a wide variety of forms, and a significant amount of experimentation using digital computers is currently under way, the theoretical basis for these models has often been elusive, and the need for a comprehensive rationale has become increasingly apparent.

Any model is an artificial representation of the real world. This artificiality is as true of a physical model of a ship as it is of a mathematical model of a transportation system. Both represent the real world in an imperfect way.

Any mathematical model in representing the real world implies a theory of behavior of the real world. Such a model is comprised of variables and relationships, and the relationships between the selected variables in the model automatically imply a theoretical construct of the manner in which the system modeled in the real world operates. In most cases, the theories behind current land development models must be deduced from their variables and relationships since extensive discussion of the theoretical framework of the models is rare.

MACROSCOPIC AND MICROSCOPIC THEORIES

Examination of current models reveals two primary classes of land development theory that may be implied from the nature of the models themselves. The first class of models is macroscopic in outlook since it deals with aggregate variables and relationships. In this approach, the theory relates to an explanation of gross land development patterns in terms of variables such as accessibility to employment and shopping centers.

An example of such a model is the gravity model, originally applied to retail trade (1), which distributes residential development in direct proportion to the size of the center and some inverse power of the distance (or travel time) from the center. This gravity model in various forms has been the best known of the macroscopic class of models and typifies the macroscopic approach in its emphasis on abstract "forces" as the cause of developing land patterns. Because of the obvious parallel of this force concept to the physical sciences, macroscopic theories are usually classified as part of the field of social physics. Macroscopic theory is closely related to geography and demography and macroscopic economics in its emphasis on aggregate relationships.

A second class of models is formulated at a more microscopic level of relationships that attempts to describe the actual decision processes of individuals influential in land development. Such models explicitly consider the goals, information availability and choice selection patterns of decision-makers.

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Examples of this second class of model are rare in land use development but quite common in microscopic economics where the classic theory of the firm is based on the optimizing concept of the business entrepeneur. A contrasting but still microscopic view of the firm is represented by the recent research of Cyert and March (2) centering on a behavioral explanation of decision-making in a business firm. This behavioral theory of the firm and its related models are based on detailed examination of organizational goals, expectations and choice processes and is representative of the microscopic approach to model-building.

The differences between macroscopic and microscopic models are really more basic than the choice of a level of aggregation. Macroscopic theory emphasizes the omnipotent forces structuring the patterns of land development independent of the decisions of individual households or businessmen associated with land development. Such a viewpoint parallels certain laws of thermodynamics that state aggregate relationships that prevail in the midst of the apparent random motion of the millions of molecules making up the gas under study. In such a framework, study of the movement patterns of the individual molecules is futile since such study does not reveal the important aggregate structure of the process.

Microscopic theory employs an opposite viewpoint that considers the key relationships to be at the level of the individual action event. To understand the process, intensive study of these individual activities is vital to a theoretical representation of the system.

Experience in land development theories and models has been too limited for even a preliminary evaluation of the merits of the macroscopic and microscopic approaches to land development modeling. Realizing this current state of the art in the field, this paper presents a particular microscopic theory of land development which has provided the basis for an operational land use simulation model in current use and offers, at the very least, a point of departure for further development of microscopic theory.

A DECISION THEORY APPROACH

A decision theoretic approach to a microscopic theory of land development involves the following sequence of research activity:

1. The identification of the key decision-makers in the land development process;
2. An examination of the goals of these decision-makers that provides a measure of the values of alternative courses of action;
3. A description of the type and quality of information available to these decision-makers and the procedures used in translating this information into expectations associated with alternative decisions; and
4. An analysis of the logic used by these decision-makers in relating goals and expectations in the selection of a desired course of action.

Successful completion of the above sequence provides the basis for both a theory of land development and a framework for a model to realize this theory in the simulation of the land development process.

DECISION-MAKERS IN RESIDENTIAL LAND DEVELOPMENT

Since residential land development occurs through a series of transactions in an economic market, the primary decision-makers must be the principals in these transactions: the buyer and the seller. In residential land-housing transactions the buyer is either a household purchasing shelter or a business investor securing a rental property. The seller is either a land developer (assuming that some development of raw land is necessary before an area is suitable for residential housing) or a builder who also serves as an intermediary in the sale of developed land.

Other persons and institutions are influential in land development even though they are not direct participants in the final transaction. Financial institutions such as commercial banks, savings and loan associations and insurance companies, play a vital role since they supply money in the form of loans to both the land developer seller and the household (or business) buyer. Indeed, such financial institutions are often in a decisive position in such transactions which could not take place without their cooperation. This influence is particularly important in a tight money market where mortgage money is in short supply. It is less influential when the money supply is adequate since competitive forces in the financial industry effectively neutralize money constraints on development.

The role of government (federal, state and local) on land development is secondary but powerful. Governmental influence is a necessary prerequisite for planning since urban plans could never be implemented if there were no governmental influence on the emerging land patterns. The governmental role is two-sided. Its most direct influence results from public works programs which provide the primary transportation, water, sewer and educational facilities necessary for any residential development. Whether the construction of such facilities tends to lead or lag land development is, of course, a key test of the real influence of these facilities.

A secondary role of government relates to the application of certain legal controls on land development such as subdivision regulations and zoning. Subdivision regulations affect the costs of the land developer by requiring him to provide certain improvements at his own expense. Zoning provides a constraint on certain transactions to the extent that it is able to withstand market pressures.

An important but more indirect influence on residential land development is exerted by private business institutions providing shopping facilities and opportunities for employment. Here the key factor is accessibility since such facilities tend to serve a limited retail or labor market area. Again, the time phasing of such development is an important consideration. If such facilities tend to follow residential development, they only reinforce existing trends. If they lead residential development into new areas, their influence can be crucial.

Since the planning, by its very nature, is expected to recommend plans and policies for government, the appropriate theory of land development for planning is one that is able to explain and predict the behavior of private (nongovernmental) decision-makers under a variety of governmental policies. The theory must be focused on the behavior of the private decision-makers in land development. Public decision-making is to be determined, not explained or predicted, based on its effect on private decision-making and the desirability of the resulting land pattern.

ECONOMIC AND BEHAVIORAL THEORIES OF RESIDENTIAL LAND DEVELOPMENT

With the decision-makers identified, the sequence of theory formulation now calls for the examination of the goals, the description of the information available to and the decision logic used by these decision makers. Two basic frameworks for a residential land development theory, the economic and the behavioral, are analyzed. Both of these frameworks involve assumptions relating to goals, information and decision logic.

A pure economic theory of land development involves the classic assumptions of the theory of the firm. The goals of land development are maximum profit for the developer and maximum utility for the household or business buyer. Perfect information relative to all variables affecting these goals is assumed so that the seller or buyer is aware of the value of each alternative. Finally, the choice of an alternative is based on maximum profit or maximum utility. Ignoring the formidable problems associated with the definition of the utility functions of the buyer and concentrating our attention on the more tangible profitability goals of the businessman-developer, the pure economic theory does offer a well-defined and logical approach to land development decision-making. Whether this well-defined and logical approach bears any resemblance to real life activity is, of course, a very different question.

The general criticisms originally voiced against the economic theory of the firm apply equally to a pure economic theory of land development. These criticisms encompass all aspects of the decision-making problem—goals, information and decision logic. The concept of a single economic goal, maximum profitability, as the guideline for all land development decisions, has been considered naive and oversimplified.

Human motivation, it is said, is much more complex, and the myth of the economic man has long since ceased to bear any relation to reality.

The criticism continues with questioning about the informational assumptions. Perfect information concerning the set of alternative decisions is rarely present in a real life situation. Such information is usually either too expensive to collect or even impossible to obtain at any price.

The final assumption, given the goals and information, is criticized in a less fundamental way. The sheer size of the computational and logical effort required in many decisions to select an optimal alternative tends to cast doubt on its practicality. Even with clear-cut goals and perfect information, the mathematical effort needed to uncover the true optimum is often staggering. That such a computational effort could be performed subconsciously by all land developers is not easily reconciled with practical experience.

Behavioral theories of the firm stress the existence of multiple goals, imperfect information and non-optimal decision logic. A land developer may well have goals relating to volume of business as well as the profitability of this business. The information available to the developer is imperfect particularly since much of this information is based on forecasts of future demand for land. Selection of the final alternative is influenced as much by the desire to avoid radical change as it is to select an optimum even within the limits of imperfect information. Some of this natural conservatism results from the realization that the information, particularly the forecasts, are imperfect. In such an atmosphere of uncertainty the desire to make haste slowly is a natural one.

While the behavioral theory is an improvement in its added degree of realism, it quickly tends to become vague and subjective, and it lacks the operational simplicity of the economic theory.

What is needed, to be sure, is a theory combining the best features of both the economic and the behavioral viewpoints. To the simplicity and common sense appeal of the economic theory, must be added the behavioral limitations brought about by the uncertainty of the forecasts of future land requirements and the natural resistance to radical change in land development trends. Such a composite theory will now be developed within the framework of a new modeling technique, recursive programming.

RECURSIVE PROGRAMMING

A Decision Framework for a Residential Land Development Theory

Recursive programming (3) is a decision simulation technique that provides for ". . . optimized decision-making over a limited time horizon on the basis of knowledge gained from past experience." (4) The limited time horizon is a direct result of the uncertainty of forecasting future land requirements. This uncertainty forces the decision-maker to base his decisions on short-term forecasts of relatively higher accuracy. Past experience continually updates these short-term forecasts over time. This same experience also alerts the land development decision-maker to the uncertainty of even these short-term forecasts and thereby discourages rapid changes in land development trends.

The analytical nature of recursive programming in its linear form is best described in the words of its originator (4):

> Recursive linear programming is a sequence of linear programming problems in which the objective function, constraint matrix and/or the right hand side parameters depend upon the primal and/or dual solution variables of the preceding linear programming problems in the sequence.

Recursive programming is a combination then of recursive simulation over time and linear programming. Each linear programming solution provides parameters for the next linear programming problem in the recursive time sequence. The recursive programming relationships for a combined economic-behavioral theory of residential land development take the following form:

$$\begin{aligned} &f(x) = \min cx(t) \\ &A'x(t) = \hat{b}'(t) \\ &A''x(t) \leq (1 + B)(t - 1) \\ &A'''x(t) \leq b'' \end{aligned}$$

where $cx(t)$ represents the cost function minimized by the land developer with the row vector c representing the costs of developing land in different areas in the region and the $x(t)$ column vector representing the amount of land developed in each area. The second relationship represents the forecast of land requirements with the total land developed in each period equal to the forecast of land requirements, $\hat{b}'(t)$, for that period. The forecast $\hat{b}'(t)$ for each type of residential land is based upon actual demand in previous periods.

$$\hat{b}'(t) = \lambda b'(t-1) + \lambda^2 b'(t-2) + \ldots + \lambda^n b'(t-n)$$

where

$$\lambda \leq 1 \text{ and } \sum_{i=1}^{n} \lambda^i = 1$$

The land demand in each past period is weighted to arrive at a forecast of future land requirements in the new time horizon. More recent periods are weighted more heavily depending on the value of the λ parameter. Higher values of λ place more weight on the recent past. Lower values conversely are more affected by the distant past. This simple form of time series extrapolation based on a "smoothing" of historical experience was extended to a more elaborate model based on household types to be described.

In addition to fulfilling the forecasts of land demand, short-term land development optimization is also restricted by the third set of relationships which tend to limit rapid changes in land development. In effect, the third class of relationship states that the new land developed in any area in any period cannot exceed some proportion of the previous development in that area. The B parameter determines the rate of development in an area that has favorable development in that area. The B parameter determines the rate of development in an area that has favorable development costs compared to rival areas in the same region. A higher value of B (B will always be less than one) will permit more rapid development of favorable areas and indicate a bolder and more risk-taking attitude on the part of developers. A lower value of B will restrict rapid development in the most economic areas and transfer development to less efficient areas. To provide for the early development in a given area, the initial condition of the constraint is established at a small value.

The third set of relationships embraces all constraints on the solutions that do not change with time. These might include land availability (capacity) restrictions in each zonal area and accessibility relationships to employment and shopping facilities in other zones. Other technical and behavioral constraints may be desirable in certain applications.

Goals, Expectations and Choice

How has the recursive programming framework provided answers to the questions of the decision-maker's goals, expectations and decision logic? The goals of the land developer decision-maker are encompassed in the recursive programming objective function. Land development is viewed as a business and the land developer as a businessman seeking to advance his own fortunes. This aspect of the theory in its assumption of the goal of maximum profitability (or minimum costs) is identical to the classic economic theory of the firm. Although it would be possible to use the developer's estimate of costs rather than the true costs, this approach was not taken here, and the costs are assumed known. The real uncertainty of these costs, however, is reflected in the restraining effect of the B parameters.

Information availability and accuracy together with the expectations associated with alternative decisions are reflected in the uncertain forecast and the resistance to radical changes provided for in the model. The informational assumptions of the model are behavioral in form and depart radically from the perfect information assumptions of the economic theory of the firm.

Within the limitations of less-than-perfect forecasts and general distrust of data accuracy, the decision logic is optimal in structure in that it selects the lowest cost combination of land development. The optimum selected, and the resulting land development sequence will differ significantly from a pure linear programming optimum given a perfect forecast of land requirements.

The composite theory reflected in the recursive programming construct is a combination of the economic and behavioral approaches to decision theory. The economic goal of profitability, as reflected in minimal costs, remains. The behavioral concepts of limited information, however, are the key to the operation of the model.

The Household Decision

The recursive programming relationships previously discussed have stressed the role of the land developer as a decision-maker. The developer has been placed in the key role of determining the location of new land development. How do the goals, expectations and decision logic of the household home buyer or renter relate to the recursive programming theoretical structure?

Inherent in the theory is the concept that the land developer determines the location of new land development based on the demand generated by the desires of households. The actual land demand in each period $b'(t)$ is determined by the households in the market for new housing. These households include households relocating within the region, new household formations, and inmigrating households. The $b'(t)$ vector of land demand in each period provides for a demand value for each type of residential land and is the result of a transformation of the household vector (number of households, by type, seeking housing) into the land demand vector. In this way, the household determines the demand for each type of residential land which is then distributed spatially by the land developer. The household population is classified into types because of the different land needs and desires of different age, income, and family-size groups within the household sector.

Household goals and decision logic also reflect in the third set of recursive programming relationships relating to accessibility constraints. Household goals relating to accessibility restrict the area of choice to those areas accessible to employment and shopping. Other household contraints on land use relationships may also be reflected in this set.

Government Plans and Controls

The third major participant in the land development process, the government, is known to exert a major influence on the emerging land use pattern. This influence is represented in all components of the recursive programming framework. The cost function is influenced by the legal codes (such as subdivision regulations) which usually determine the proportion of land development costs to be borne by the private developer. Public works programs (such as highway and transit systems) determine the accessibility of potential residential areas to employment, shopping, and recreational facilities. Accessibility constraints are represented in the third set of constraint relationships in the recursive programming model. These accessibility constraints prevent land development in areas outside of specified travel-time limits from employment and commercial centers. Other public works (for example, sewer systems in combination with the legal framework) provide other constraints on certain types of residential development in some areas.

Since the primary purpose of a theory of land development for urban and regional planning is to provide the knowledge necessary to implement certain plan designs, the usual approach to application of the theory will be to test the effects of government policies (such as those related to land development costs) and public works on the course of land development. Experimental test and modification of these policies allows for the determination of a set of policies consistent with the target plan design.

MODEL IMPLEMENTATION

Variables and Relationships

The implementation of the recursive programming theory of land development involves the detailed specification of a set of variables and the estimation of a set of associated parameters. This implementation is best presented in terms of the general matrix of variables and parameters previously discussed. If each element of each matrix and vector can be identified as to physical meaning, the application will become more real and vital. The variable vector and each parameter vector and matrix are presented sequentially.

1. The x variable vector. The elements of this vector represent the land developed by residential-density class in each area of the zonal grid defined for the model. Because the type of soil provides the basis for the estimation of costs, subareas within each area will exist depending on the number of types of soil in that area. The size of the vector will depend on the number of soil groups in all of the areas, the number of zonal areas, and the number of residential-density classes. If each of 50 zonal areas had 3 soil types and 3 density classes represented, there would be 450 elements in the x vector.
2. The c cost parameter vector. The elements of this vector represent the cost of developing an acre of land of a given density on a given soil type in a specified zonal area. The number of elements will correspond to the x variable vector since a cost element is required for each x vector element.
3. The A' design standards parameter matrix. The elements of this matrix represent the amount of primary and service land required to provide an acre of residential land of a given residential-density class. Service land requirements include land for streets, local shopping centers, local school sites, and local recreational areas. An element value of 1. 5 would indicate that one-half acre of service land is needed for each acre of residential land. The number of rows in this matrix depends on the number of residential-density classes. The number of columns depends on the size of the x variable vector.
4. The $\hat{b}'(t)$ land demand forecast exogenous variable vector. The elements of this vector represent the forecasts of regional demand for each residential density class. The size of the vector depends on the number of residential-density classes. This vector is exogenous to the main model and is externally programmed to change every recursive time interval. A number of methods might be used to prepare this forecast. In the current application, a land use demand forecasting submodel based on a household typology is used to generate the forecast. A transformation matrix is used to convert households by type into land demand by residential-density class.
5. The A'' behavioral constraint matrix. The elements of this matrix are all unity. The number of rows in the matrix depends on the product of the number of zonal areas and the number of residential-density classes. The number of columns correspond to the x variable vector.
6. The $(1 + B)\,(t - 1)$ variable vector. The elements of this vector represent the permissible development of each residential-density class in each zonal area based on some proportional increases over previous development. The value of the B coefficient depends on the behavioral resistance to change among local land developers. The number of elements is identical to the rows of the A'' matrix.
7. The A''' accessibility and zonal capacity matrix. A variety of constraint relationships is represented by this third matrix set. In the accessibility submatrix, all zonal areas accessible to a given shopping or employment center are represented by unity element values. Other zones are given zero element values. One row in the matrix will be required for each center. The zonal capacity submatrix is an extremely low-density matrix with a maximum of three non-zero elements (one each residential-density class) for each row of the matrix. This matrix and its associated right-hand

side constrain the total land developed to zonal land capacity. One row of the matrix is required for each zonal area.

8. The b'' accessibility and zonal capacity vector. In the accessibility subvector the element values represent the amount of residential land within the travel time service area that can be supported by each center. One element is needed for each employment and shopping center. The zonal capacity subvector elements represent the land capacity of that zone. One element is needed for each zone.

Parameter Estimation

Model parameters were estimated from sources independent of the land development history in the region. Regression analysis of variable histories was not used for parameter estimation. Such an approach allows for meaningful historical tests of the theory and model since parameters are estimated independently.

Cost parameters were based on engineering estimates of land development costs depending on the type of soil in the area. With this cost-soil type relationship established, the regional soil survey allowed for the estimation of development in all areas of the region. Raw land values were based on equalized assessed valuations of the land.

The design standards relating to the amount of service land required to support residential land developed were based on both historical ratios and normative design standards. The regional land use inventory was used to determine existing relationship between primary and service land in residential areas.

The behavioral B coefficients were the only parameters estimated by analysis of historical time series. Since these coefficients determine a nonlinear upperbound constraint, linear regression analysis is not suitable. A partially experimental method of nonlinear regression may be used to estimate these parameters.

Accessibility criteria for the household types represented in the model were determined from an analysis of the travel-time habits of sampled households. This analysis established the market areas of the shopping and employment centers.

Zonal capacities were determined from the "developable land" indicated in the land use inventory.

Early experimental experience with the model is more fully described in a technical report by the Southeastern Wisconsin Regional Planning Commission (5).

Plan Design and Public Policy

Residential land development theory must be related to the overall urban-regional planning problem in order to be meaningful and useful. The urban regional planning problem solution may be viewed as a three-stage sequence:

1. Determining the current state of the region;
2. Designing a plan for a desired future state of the region that satisfies the plan objectives; and
3. Developing public policies and programs necessary to transform the region from its current state into the desired future state.

Residential land development theory is related almost exclusively to the third stage of this planning sequence. Its relationship to the current state of the region is important only as a means to explain the historical decision-making that led to the current pattern. An understanding of this historical development, aside from its more academic interest, is important only insofar as it leads to a clearer understanding of the third stage relating to future land development.

The theory should not be used to design plans for the desired future state of the region unless these plans are intended only as a means of perpetuating existing trends. The most significant confusion concerning the application of land development theory seems to revolve about the approach to plan design. Since land development theory is essentially positivistic (what is) rather than normative (what should be) in nature, its use in plan design usually represents a perversion of the worst kind.

The final stage of urban-regional plan development is closely linked with an explicit or implicit theory of land development. The transition to a desired future land pattern involves a complex decision-making process only partially controlled by the planner. Attempts to influence or modify this process will be abortive unless they are based on a soundly conceived and experimentally verified residential land development theory. The recursive programming theory of residential land development may well provide at least a partial answer to this need.

REFERENCES

1. Reilly, W. J. Methods for the Study of Retail Relationships. Univ. of Texas Bull. No. 2944, Nov. 1929.
2. Cyert, Richard M., and March, James G. A Behavioral Theory of the Firm. Prentice-Hall, Englewood Cliffs, N.J., 1963.
3. Day, Richard H. Recursive Programming and Production Response. North Holland Publishing Company, Amsterdam, 1963.
4. Day, Richard H. Linear Programming and Related Computations. Dept. of Agriculture, Washington, D.C., 1964.
5. Technical Report No. 3. The Land Use Plan Design Model and the Land Use Simulation Model. Southeastern Wisconsin Regional Planning Commission, Waukesha, Wis., Jan., 1966.

Discussion of Land Use Forecasting Concepts

IRA S. LOWRY, The RAND Corporation. —The papers presented here form a rather neat progression from the general to the specific:

1. An essay on scientific method and its application to model-building;
2. An essay on some recurrent strategic problems in land use and transportation models; and
3. An exposition of an explicit model of residential land development.

I will comment on the first of these papers and on the last.

It is always a pleasure to read an essay by Britton Harris. This one is no exception. The ideas are well formulated, the illustrations are both lucid and engaging, and the prose style is first-rate. The essay is much too rich to be profitably summarized by a discussant, so I have picked out several of its themes for comment.

Simulation. I am mildly distressed by the use of the term "simulation" as it appears in Mr. Harris' title and repeatedly through the paper. He tells us immediately what he means by the term: ". . . the reproduction in some recognizable form of certain aspects of human behavior or of the performance of mechanical systems, or of a combination of these two." In other words, "modeling a system." Elsewhere, he speaks of a simulation model, a phrase surely redundant in view of his definition.

Such equivocal usage is unfortunately general among model-builders. The difficulty is that there also exists a particular class of quantitative models commonly called simulation models; these are most clearly distinguished from other quantitative and mathematical models of the same phenomenon by the method of solution. If we think of a set of models of a given phenomenon or real-world system as each identifiable with a set of simultaneous equations, the simulation model is one which is meant to be solved by numerical substitution rather than by analysis. The use of this brute-force technique is most often associated with large models whose logical closure is not self-evident, and also with Monte Carlo methods of generating inputs or intermediate values for certain of the variables.

While simulation models in this sense have in fact been applied to conventional forecasting problems, this is not, I submit, their proper métier. Simulation is a very useful if inelegant technique for exploring the homeostatic properties of a complex system, and is really most serviceable when applied to problems of system-design in which homeostasis is an important design criterion.

System Mechanics and Decision Theory. Among my colleagues, both in urban systems research and in economics, there is a persistent myth to the effect that each real-world system can in principle be reduced to a set of interacting elements which are themselves irreducible. These elements are called "decision units," and we are warned that unless we understand the behavior of the decision units, we can never successfully model the system. The first error in this argument is the notion that the decision-unit—say, a household, an automobile driver, a corporation—is irreducible. It is rather a system in its own right, also composed of elements, ad infinitum. The argument also ignores the fact that the only reasonably successful models so far produced for large human systems do not deal in decision units, but rather with much more aggregative systems-mechanics.

But the myth persists, and macro-analysis has acquired a bad name in the social sciences. When it comes to modeling urban systems, nearly everyone except J. Douglas Carroll apologizes for resorting to a macro-analytic approach which fails to exploit the infinite variety of behavioral possibilities at the level of decision-units.

I think that Mr. Harris gives an excellent account of the dilemma of urban systems research with respect to the level of analysis. The theme is perhaps the most persistent of his essay. If we approach the problem at the most aggregative level, the case material on which a model of systems mechanics may be based is "limited in extent, and experimental manipulation is both extremely slow and vastly expensive." On the other hand, if we tackle the decision units, we not only find that their behavior is more erratic than that of the system, but we are also unable to work out the mechanics of aggregation which will get us back to the system level. And it is, after all, the performance of the system in which we are primarily interested.

Heretofore, Harris has always given priority to micro-analytic research as the key to success in modeling urban systems. For the first time, to my notice, he has now reversed his priorities, arguing for the study of aggregative systems mechanics "on the grounds that the relevant experiments to test our understanding of the behavior of decision units can probably not be performed without it."

My own view is that success is where you find it. The construction of a truly comprehensive theory of the behavior of a large system may indeed lead to greater and greater disaggregation, further reduction of the irreducible. But building a model whose solution can be identified with a system's behavior within the environment of interest and with an acceptable level of verisimilitude may be much less taxing at higher levels of aggregation. As a matter of personal style, I tend to look to behavioral models of individual decision-units mostly for clues and hunches about the nature of highly aggregated system mechanics. The method is fallible, but I think, fruitful.

Mappings and Multiplications of Mappings. I like the description of the relationship between a theory and a phenomenon—that is between a theory and a real-world event or system of events. He calls this relationship a mapping, in which explicit correspondences are postulated between the elements of the theoretical system and the elements of the real-world system. The exactness of correspondence may vary; he distinguishes the crudest case as that of analogy, and he calls the complete one-to-one mapping of a theory onto a real-world system an isomorphism. In between, he recognizes explicit but imperfect mappings which he calls homomorphisms.

It is perhaps unfortunate in the essay that the passage just summarized does not lead directly to the discussion of the relationship of theories and models—unfortunate because this relationship also can be profitably conceived as a mapping. With some hesitation, Harris defines a model as "an experimental design based on a theory." We expect to find, then, correspondences between the elements of the theory and those of the model. There should also obviously be correspondences between the elements of a model and those of the real-world system which is being modeled. In experimental science, we typically thus have a multiplication of mappings—from theory to model to phenomenon. The direct mapping from theory to phenomenon is the device of the armchair or speculative scientist.

I think the point is important because it reveals two quite disjointed contexts for error. Our mapping of a theory into a model may be incorrect or ambiguous; and our mapping of the model into the real world may also be incorrect or ambiguous. On the other hand, this perspective also reveals the possibility that we may, by accident or intuition, have a good model along with a bad theory, or even without theory.

Let me add parenthetically that of my colleagues in the model-building field I can readily say that some are extremely proficient at mapping theories into models, and some are extremely proficient at mapping models into phenomena; but I do not number among my acquaintances anyone who is competent at both.

These last remarks provide a convenient point of departure for my reactions to Kenneth Schlager's paper. He also makes distinctions between a theory, a model, and a real-world phenomenon. He complains that "the theories behind current land development models must be deduced from their variables and relationships since extensive discussion of the theoretical framework is rare." And, in opposition to the dominant style of macro-models for land use prediction, he proposes a micro-model with an explicit basis in "decision theory."

> A decision theoretic approach to a microscopic theory of land development involves the following sequence of research activity:
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> 1. The identification of the key decision-makers in the land development process;
> 2. An examination of the goals of these decision-makers that provides a measure of the values of alternative courses of action;
> 3. A description of the type and quality of information available to these decision-makers and the procedures used in translating this information into expectations associated with alternative decisions; and
> 4. An analysis of the logic used by these decision-makers in relating goals and expectations in the selection of a desired course of action.
>
> Successful completion of the above sequence provides the basis for both a theory of land development and a framework for a model to realize this theory in the simulation of the land development process.

Mr. Schlager goes through these steps in an exceedingly casual way for someone concerned with theoretical rigor. At all events, he comes out with three propositions about the behavior of land-developers:

1. They may have goals other than profits,
2. Their information is imperfect and they know it, and
3. Their decision-logic has a conservative bias.

His model, which is alleged to correspond to this theory, does not include a single variable which can be identified with those of the decision-paradigm for an individual land-developer. His model, as he explained, is a recursive linear program whose solution is that distribution of newly developed land which results in the minimum total cost of land development for a region, given aggregate demand forecasts for K types of housing. The solution is constrained by limits on zonal capacity, and by a binary rule governing colocation of households and shopping facilities. It is also constrained by upper bounds set on the rate of development in each zone. The solution vector of his model corresponds in the real world to the outcome of a market process involving many land-developers, many households, and assorted other parties. If this market process can be mapped onto the decision paradigm which Schlager presents as his "theory," it is only in the sense of analogy; certainly we are far from isomorphism.

What are, in fact, the correspondences? He emphasizes three which he considers strategic. The theoretical principle of multiple goals is represented in the model by the use of an objective function which minimizes cost rather than maximizes profit. The principle of imperfect information is represented by a demand forecast constructed from an exponentially-weighted time series of actual demands. The principle of conservatism in decision-making is represented by the local rate-of-development constraint which is based on past local rates of development.

If, in Schlager's mapping, the individual land-developer as decision-maker is blown up into a market system by scalar multiplication, the other decision-makers are very nearly relegated to the null space of the mapping. None of those listed by him as relevant—households, local governments, financial institutions—draws any information from the market, and there is no suggestion in the model that they too have decisions to make, alternatives, and trade-offs to consider in response to "moves" by the land-developer.

In fact, if I may put Mr. Schlager in bad company, he has done very much what I might have done under the same circumstances: pondered the paradigm of individual decision for hunches as to the kind of model that might work. But he has not in any sense established in his paper a close and rigorous correspondence between his model and his decision-theory.

I suppose it is apparent that I find fault with Schlager's mapping of his theory into his model. Let me now turn to his other mapping, from the model into the real world. This is the section of his paper where he identifies development costs with soil types, the demand for each type of housing with a linear combination of household types, accessibility of a zone with travel-time to the nearest shopping center, etc. The really crucial fact about this mapping is that he identifies the solution to his recursive linear program with a pattern of land development over time.

I think that there is a good chance that he will be able to show a reasonable correspondence between the solution to his model and the actual development pattern so long as he sticks to ex post facto prediction. Schlager makes the point that his parameters are estimated "from sources independent of the land development history of the region. . . . Such an approach allows for meaningful historical tests of the theory and model." But a few paragraphs further, he allows one exception, the B coefficients which are to be estimated from historical time series, apparently the same time series which are to provide the test of his model.

Because of his condensed notation, it is not clear to me whether B is a single number, a drift parameter whose value changes systematically with time, or a vector of numbers each specific to a local area within the region. If the last interpretation is correct, B is our old friend the k-factor under an assumed name. The expression containing B will very nearly be the error-term of the forecast which would have been made by a similar model lacking the B-type constraint.

If, on the other hand, B is a drift parameter or even a single number fitted from the time series which is then used to test the model's solution, it still offers some help in constraining the solution to match the historical pattern of development. He says that "the value of the B coefficient depends on behavioral resistance to change among local land developers." It is obvious that the variable thus defined is not measurable by any techniques at his disposal. Rather he will measure the serial correlation of development rates in local areas.

This is to my mind a better approach than the naive trend forecasting method not unknown in land-use planning. It is better because trend is here used as an upper bound rather than as a best estimate. The solution to Schlager's linear program also has certain cost and accessibility constraints which in principle make sense, although I am surprised to learn that in Wisconsin, soil type is so important a determinant of land-development costs.

In summary, I think Schlager's model might meet the tests of ex post facto prediction because (a) it contains some quite relevant variables, and (b) it is constrained by observed events of the back-casting period. I do not think, however, that it owes much to decision theory except inspiration, and on this ground I take exception to the lecture on theoretical rigor with which he introduces his model.

BRITTON HARRIS, Closure—One of the pleasant aspects of discourse with Mr. Lowry is the fact that our meetings frequently uncover rewarding and interesting differences, but seldom lead to sharp disagreements.

On the subject of simulation there could be endless debate, largely over semantics. I think the kernel of the problem is to be found in the fact that even many deterministic system descriptions resist analytic solution and hence, while analytic in nature, appear to be solved by simulation. As I tried to imply in my paper, some less clumsy methods should be sought for exploring not only the homeostatic, but also the more general dynamic properties of the systems in which we are interested. I agree that when we have analytic means of doing this, we may be forced to abandon the term "simulation," even though in the most literal etymological sense it may be correct.

I am inclined to disagree with Lowry that system elements occur in infinitely nested sets. In any case, however, there are levels of relevance. Systems theory surely can be used to demonstrate that a sulfur atom in my left toe-nail is hardly a suitable system for study in relation to metropolitan affairs. We can stop disaggregating our systems at the subsystem which we call a man and leave his internal functioning to medicine and psychology. Here, Lowry's attribution to me of a change in viewpoint is only partly correct. In the past while I may have preached micro-analysis, I have practiced macro-analysis. Conversely, while at present I acknowledge my emphasis on macro-analysis, I still maintain that we will ultimately make progress only by finding the appropriate bridge from man to the social system and the metropolitan system. Success may indeed be where you find it, but one of the purposes of theory is to suggest where to look. I still think we ought to look. I still think we ought to look under this bridge.

I like Lowry's comments on the multiplication of mappings, but I cannot go all the way with his method of dichotomizing theory and models. The interesting case which he identifies of a good model and a bad theory indeed gives us reason to ponder the whole situation. This is indeed armchair theorizing, but it does not correspond to my concept of theory at all.

KENNETH J. SCHLAGER, Closure—There are three basic objections raised by Jack Lowry that I will comment on in my rebuttal.

1. The first objection relates to the mapping of theory into models and the mapping of models into real-life.
2. The second relates to the estimation of the B factors in the model.
3. The third relates to the use of soil data for the estimation of residential land development costs.

In reference to the question about the relationship between the proposed model and the theory from which it is introduced, the concept of an analogy is characterized as crude. Lowry perhaps would like to see a direct, or more specifically, a detailed isomorphic correspondence between the elements of the theory and the elements of the model. If such a correspondence should take the form of an objective-by-objective, information-by-information, and decision-by-decision correspondence, he knows as well as I do that such a model is not now possible within the computational state of the art. The many types of households and land developers make such a model computationally, if not conceptually and statistically, an impossibility. But does that mean a microscopic model is impossible? Not at all, since the model proposed is microscopic in the sense of an analogy. The development of land in each zonal subdivision of the model is depicted as a "flow" controlled by the decisions of the land developer. No apologies need be made for analog models since almost all the advances in the application of science and technology to engineering, which is quite microscopic because engineering problems are rarely solved in the aggregate, have resulted from the use of hydraulic-electrical-mechanical analogies. To ignore the role of analog models is to ignore the whole history of the application of scientific theory. Land development models, as well as physical models in the microscopic sense, can benefit from the application of analogy. Isomorphic models may be of aesthetic interest to the theoretician but rarely have important meaning in application.

The estimation of the B factors used in the model was not the result of a time series analysis of the history of the system being studied, but the result of investigations of growth rates in areas at the subdivision level. For this reason the implication that the B factors were used as disguised k factors to improve the accuracy of the model is without foundation.

The objection that questions the relationship between land development costs and soil resources is a rather sad commentary on the tremendous gap that exists between the theoretical model builder and the realities he is trying to model. Anyone who has had any contact, direct or indirect, with land development will testify as to the importance of soils in development costs. These soil differences can change the cost of development by as much as 100 percent or more in a particular area. It is true that some areas will have greater variations in the types of soil than others and that the variations in development costs will fluctuate correspondingly. But the fact remains that insofar as soil differences do exist, they provide a sound method for the estimation of land development costs in any area.

In summary, the response to the three objections are:

1. An analogy may and usually does provide a basis for a microscopic model of a real-life phenomenon.
2. The B factors in the model were not estimated from historical output with which the model was being compared.
3. Soil resource data provide a sound and perhaps the only basis for the estimation of land development costs.